

## CLAIMS

1. A NO<sub>x</sub> abatement system, comprising:  
a first NO<sub>x</sub> adsorber (18) disposed in-line, capable of being disposed downstream of and in fluid communication with an engine (12);  
a selective catalytic reduction catalyst (20) disposed in-line,  
5 downstream of and in direct fluid communication with the first NO<sub>x</sub> adsorber (18), wherein the selective catalytic reduction catalyst (20) is capable of storing ammonia; and  
an off-line reformer (24) disposed in selective communication with and upstream of the first NO<sub>x</sub> adsorber (18) and the selective catalytic reduction catalyst  
10 (20), wherein the reformer (24) is capable of producing a reformat comprising primarily hydrogen and carbon monoxide.
2. The system of Claim 1, further comprising a first oxidation catalyst (14) and a particulate filter (16) disposed in-line, upstream of and in fluid communication with the first NO<sub>x</sub> adsorber (18), wherein the particulate filter (16) comprises a water gas shift catalyst.
3. The system of Claim 2, further comprising a second oxidation catalyst (36) disposed in-line, downstream of and in direct fluid communication with the selective catalytic reduction catalyst (20), wherein the second oxidation (36) comprises a zeolite.
4. The system of Claim 3, wherein the second oxidation catalyst (36) comprises a zeolite under-layer comprising the zeolite, wherein the zeolite under-layer is catalytic metal free.
5. The system of Claim 3, wherein the zeolite is present in an amount greater than or equal to about 20 wt%, based on the total weight of the zeolite under-layer.

6. The system of Claim 3, wherein the zeolite has a Si/Al molar ratio of greater than or equal to about 12.

7. The system of Claim 2, wherein the water gas shift catalyst is capable of maintaining, within about  $\pm 2$  vol%, a hydrogen concentration in an exhaust stream passing through the particulate filter (16), based upon a total volume of hydrogen entering the particulate filter (16) compared to a total volume of hydrogen  
5 exiting the particulate filter (16).

8. The system of Claim 2, wherein the water gas shift catalyst is capable of increasing a hydrogen concentration in an exhaust stream to greater than or equal to about 20 vol.%, based upon a total volume of the exhaust stream exiting the particulate filter (16).

9. The system of Claim 1, further comprising a first oxidation catalyst (14) and a particulate filter (16) disposed in-line, upstream of and in fluid communication with the first NO<sub>x</sub> adsorber (18), wherein the first oxidation catalyst (14) comprises an oxidation catalyst capable of partially oxidizing greater than or  
5 equal to about 60 vol.% of hydrocarbons, based upon a total amount of hydrocarbons in an exhaust stream entering the first oxidation catalyst (14).

10. The system of Claim 9, wherein the oxidation catalyst (14) is capable of partially oxidizing greater than or equal to about 75 vol% of the hydrocarbons.

11. The system of Claim 10, wherein the oxidation catalyst (14) is capable of partially oxidizing greater than or equal to about 85 vol% of the hydrocarbons.

12. The system of Claim 9, wherein the oxidation catalyst (14) comprises:

a Part 1 component comprising a Part 1 support material having an agglomeration of primary particles, wherein an agglomeration size, measured along a major diameter, is about 5 micrometers to about 15 micrometers, and wherein the primary particle size is less than or equal to about 300 nanometers; and

a Part 2 component comprises a primary particle size of less than or equal to about 500 nanometers and a Part 2 agglomerate size of less than or equal to about 0.5 micrometers.

13. The system of Claim 12, wherein the ratio of the Part 1 component to the Part 2 component is about 80:20 to about 20:80.

14. The system of Claim 12, wherein the Part 2 component comprises a solid solution selected from the group consisting of titanium-zirconium oxide, yttrium-zirconium oxide, barium-zirconium oxide, lanthanum-titanium oxide and the like, as well as combinations comprising at least one of the foregoing,

15. The system of Claim 1, further comprising an in-line by-pass conduit (34) capable of being disposed in fluid communication with the engine (12) and the selective catalytic reduction catalyst (20), and an in-line by-pass valve (30) in fluid communication with the by-pass conduit (34) and the first NO<sub>x</sub> adsorber (18), wherein the by-pass valve (30) is capable of diverting an exhaust stream around the first NO<sub>x</sub> adsorber (18) via the by-pass conduit (34) to the selective catalytic reduction catalyst (20).

16. The system of Claim 15, further comprising a second NO<sub>x</sub> adsorber (118) disposed downstream of the by-pass valve (30) and upstream of the selective catalytic reduction catalyst (20) such that when the exhaust stream is diverted around the first NO<sub>x</sub> adsorber (18) the exhaust stream passes through the  
5 second NO<sub>x</sub> adsorber (118) prior to entering the selective catalytic reduction catalyst (20).

17. The system of Claim 1, further comprising:  
an off-line burner (38) disposed upstream of and in fluid communication with the reformer (24); and  
an off-line reactor (44) in fluid communication with and disposed  
5 downstream of the reformer (24), wherein the reactor (44) comprises an ammonia forming catalyst.

18. The system of Claim 17, further comprising an off-line heat exchange (64) device in thermal communication with a passenger compartment, wherein the heat exchange device is downstream of and in fluid communication with the burner (38).

19. The system of Claim 1, wherein the first NO<sub>x</sub> adsorber (18) comprises a catalyst capable of converting adsorbed NO<sub>x</sub> to ammonia.

20. The system of Claim 1, wherein the first NO<sub>x</sub> adsorber (18) comprises a NO<sub>x</sub> trapping material and a sufficient amount of a hydrophobic material to render the NO<sub>x</sub> trapping material hydrophobic.

21. The system of Claim 1, wherein the hydrophobic material is present in an amount of about 0.1 wt% to about 2 wt%, based on a NO<sub>x</sub> combined weight.

22. The system of Claim 1, wherein the reformer (24) comprises a hexaaluminate support.

23. The system of Claim 1, wherein the NO<sub>x</sub> adsorber (18) comprises a substrate and a protective coating coated on the substrate, wherein the protective coating comprises phosphate.

24. A method of NO<sub>x</sub> abatement, comprising:  
storing engine NO<sub>x</sub> from an exhaust stream in a initial NO<sub>x</sub> adsorber (18) during a storage phase;  
forming reformat comprising primarily hydrogen and carbon  
5 monoxide in an off-line reformer (24) during a regeneration phase;  
reacting the reformat with the stored NO<sub>x</sub> to produce greater than or equal to about 5,000 ppm ammonia during the regeneration phase; and  
storing the ammonia in a selective catalytic reduction catalyst (20) during the regeneration phase.

25. The method of Claim 24, further comprising by-passing the exhaust stream around the initial NO<sub>x</sub> adsorber (18) during the regeneration phase.

26. The method of Claim 24, further comprising reacting NO<sub>x</sub> in the by-passed exhaust stream with the stored ammonia.

27. The method of Claim 24, further comprising storing NO<sub>x</sub> in the by-passed exhaust stream in a by-pass NO<sub>x</sub> adsorber (118) during the regeneration phase, and reacting the stored by-pass NO<sub>x</sub> with the reformat during a storage phase of the initial NO<sub>x</sub> adsorber (18).

28. The method of Claim 24, further comprising reacting exhaust gas recirculation in the reformer (24) to produce hydrogen.

29. The method of Claim 24, further comprising filtering the exhaust stream; and water gas shifting water in the exhaust stream in a filter (14) to hydrogen prior to storing the engine NO<sub>x</sub>;
- 5 wherein the water gas shifted stream comprises greater than or equal to about 20 vol% hydrogen exiting the filter, based upon a total volume of the exhaust stream exiting the filter.
30. The method of Claim 29, wherein the water gas shifted stream comprises greater than or equal to about 26 vol% hydrogen exiting the filter, based upon a total volume of the exhaust stream exiting the filter.
31. The method of Claim 24, further comprising partially oxidizing hydrocarbons in the exhaust stream prior to storing the engine NO<sub>x</sub>, wherein greater than or equal to about 60 vol.% of the hydrocarbons are partially oxidized, based upon a total volume of hydrocarbons in the exhaust stream prior to the partial oxidation.
32. The method of Claim 31, wherein greater than or equal to about 75 vol% of the hydrocarbons are partially oxidized.
33. The method of Claim 32, wherein greater than or equal to about 85 vol% of the hydrocarbons are partially oxidized.

34. A NO<sub>x</sub> abatement system, comprising:  
an in-line selective catalytic reduction catalyst (20) capable of being disposed in fluid communication with an engine (12), wherein the selective catalytic reduction catalyst (20) is capable of storing ammonia;  
5 an off-line reformer (24) in fluid communication with the selective catalytic reduction catalyst (20), wherein the reformer (24) is capable of producing a reformat (24) comprising primarily hydrogen and carbon monoxide; and  
an off-line reactor (44) in fluid communication with and downstream of the reformer (24), wherein the reactor (44) comprises an ammonia forming catalyst.

35. The system of Claim 34, further comprising an off-line burner (38) in fluid communication with and upstream of the reformer (24) and the reactor (44).

36. The system of Claim 35, further comprising an off-line mixing chamber (42) disposed upstream of the reactor (44), downstream of and in fluid communication with the reformer (24), and in direct fluid communication with the burner (38).

37. A method of NO<sub>x</sub> abatement, comprising:  
burning fuel off-line to form burner NO<sub>x</sub>;  
forming a reformat comprising primarily hydrogen and carbon monoxide, off-line;  
reacting the burner NO<sub>x</sub> with the reformat to form ammonia, off-line;  
5 storing the ammonia in an in-line selective catalytic reduction catalyst;  
introducing engine NO<sub>x</sub> to the selective catalytic reduction catalyst (20); and reacting the engine NO<sub>x</sub> with the ammonia.

38. The method of Claim 37, wherein the burner NO<sub>x</sub> and the reformat are reacted at a temperature of about 120°C to about 400°C and a pressure of about 15 kPa to about 150 kPa.

39. The method of Claim 37, further comprising periodically regenerating the selective reduction catalyst (20) by periodically forming the ammonia and periodically introducing the ammonia to the selective catalytic reduction catalyst (20).

40. The method of Claim 37, further comprising heating a passenger compartment of a vehicle with the burner NO<sub>x</sub>.

41. A NO<sub>x</sub> abatement system, comprising:  
an off-line membrane (70) capable of inhibiting passage of oxygen through the membrane (70);  
an off-line reformer (82) disposed downstream of and in fluid  
5 communication with the membrane (70) and a fuel source (26), wherein the reformer (24) is capable of producing ammonia from fuel and nitrogen; and  
an in-line selective catalytic reduction catalyst (20) disposed downstream of and in fluid communication the reformer (82), wherein the selective catalytic reduction catalyst (20) is capable of storing ammonia and capable of  
10 receiving NO<sub>x</sub> from an engine (12).

42. The system of Claim 41, wherein the reformer (82) comprises a pressure controlled container capable of operating at a pressure of about 20 atmospheres to about 100 atmospheres.

43. The system of Claim 41, wherein the pressure is about 20 atmospheres to about 40 atmospheres.



44. A method of NO<sub>x</sub> abatement, comprising:  
passing air having an initial nitrogen concentration through a  
membrane (70) to form a membrane effluent having a subsequent nitrogen  
concentration, wherein the subsequent nitrogen concentration is greater than the initial  
5 concentration;  
mixing the membrane effluent and a fuel (26) in a mixing chamber  
disposed upstream of and in fluid communication with a reformer (82);  
introducing the mixed air and fuel into the reformer (82) to produce a  
reformate comprising ammonia;  
10 periodically introducing the ammonia to a selective catalytic reductive  
catalyst (20) to regenerate the catalyst; and  
reacting the ammonia stored in the selective catalytic reductive catalyst  
(20) with NO<sub>x</sub> in an exhaust fluid.

45. A NO<sub>x</sub> abatement system, comprising:  
an in-line non-thermal plasma reactor (86) capable of being disposed  
downstream of and in fluid communication with an engine (12);  
an in-line selective catalytic reduction catalyst (20) disposed  
5 downstream of and in direct fluid communication with the non-thermal plasma reactor  
(86); and  
an off-line reformer (24) disposed upstream of and in fluid  
communication with the selective catalytic reduction catalyst (20).

46. The system of Claim 45, wherein the non-thermal plasma  
reactor (86) is capable of controlling a ratio of NO to NO<sub>2</sub> in an exhaust stream from  
the engine, wherein the ratio can be controlled to about 1:0.6 to about 1:1.5 at  
temperatures less than or equal to about 200°C.

47. A method of NO<sub>x</sub> abatement, comprising:  
introducing an engine exhaust stream to a non-thermal plasma reactor  
(86);  
reacting NO<sub>x</sub> in the exhaust stream to form a non-thermal plasma  
reactor effluent having a ratio of NO to NO<sub>2</sub> of about 1:0.6 to about 1:1.5 at  
5 temperatures of less than or equal to about 200°C;  
forming reformat comprising primarily hydrogen and carbon  
monoxide;  
introducing the non-thermal plasma reactor effluent and the reformat  
to a selective reduction catalyst; and  
10 reducing the NO<sub>x</sub> to nitrogen.
48. The method of Claim 47, wherein the reformat is periodically  
introduced to the selective catalytic reduction catalyst (20).